Virtual Research Presentation Conference

Advanced Navigation for Future Mars Rotorcraft

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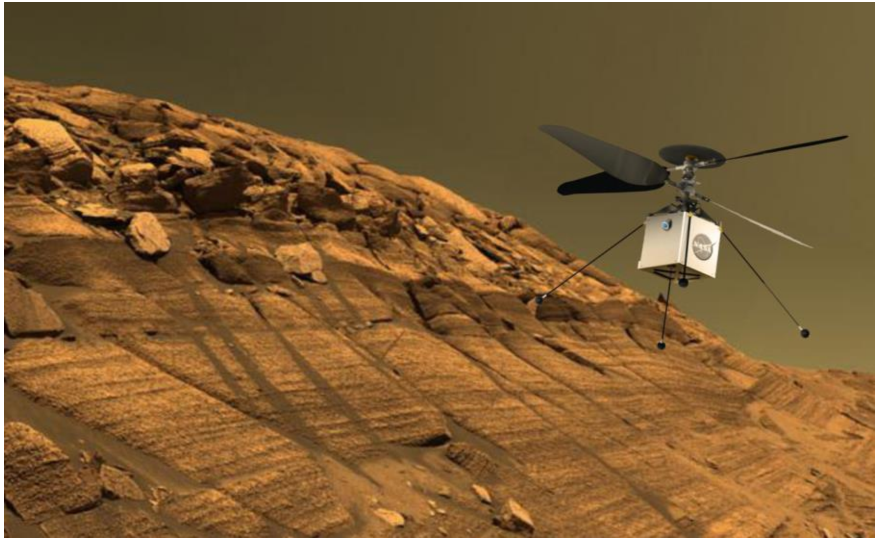
Program: Strategic Initiative

RPC-189

Jet Propulsion Laboratory
California Institute of Technology

Introduction



Abstract

On-board Mars2020 the Mars Helicopter *Ingenuity* is heading to Mars for the first controlled flight on another planet.

Designed as a technology demonstration, *Ingenuity* has limited navigation capabilities to reduce risk and development cost, and can only fly over benign, flat and level terrain.

But if successful, it could enable a new era of Mars exploration:

Envision a future Mars Science Helicopter (MSH) that can deploy an onboard instrument suite at science locations over complex terrain.

The *Advanced Navigation for Future Mars Rotorcraft* task seeks to develop autonomous navigation and safe landing technologies necessary for rotorcraft access to any terrain on Mars.

Problem Description

All terrain access for an autonomous rotorcraft requires 3 main components that are needed for a Mars Science Helicopter that could fly on Mars as early as in the mid 2020s:

- Robust, all-terrain pose estimation – without any human interaction – to enable autonomous flights over complex non-flat topology: into craters, along cliffs or drop-offs (Focus of FY19).
- Onboard landing hazard detection and avoidance to enable autonomous safe landing in terrain with landing hazards – in previously not visited terrain, or in emergencies (Focus of FY20).
- Onboard map-based localization to provide global reference position – to enable precision navigation to distant science targets (Focus of FY21).

Main focus of this presentation !

Relevance to NASA and JPL

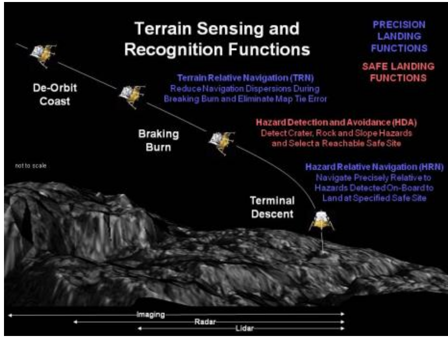
A highly capable Mars Science Helicopter (MSH) could have major impacts on future Mars exploration by enabling high priority investigations addressing all four of the top-level themes of Mars science (Life, Climate, Geology, and Prepare for Human Exploration) [1].

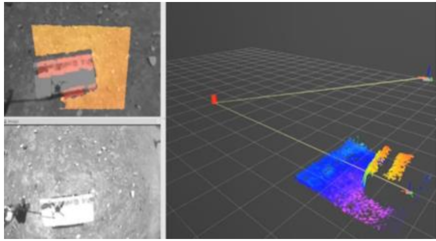
This includes acquiring imagery at much higher resolution than is possible from orbit, over much more area and in more extreme terrain than can be accessed by a rover, to establish regional geologic context, to map terrain layering that reveals climate history, to examine surface morphology and composition where rovers can't reach, and to assess the safety of candidate landing sites for future human exploration.

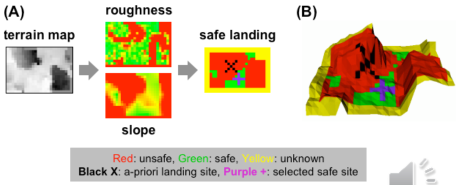
Current State-of-the-Art

(landing site detection for rotorcraft)

Approach	Description	3D Reconstruction Sensor	Why can't we use it ?
ALHAT / LVS [3]	Combines precision landing with safe landing functions	Lidar	• Outside MSH size weight and power (SWaP) constraint
Vision-based roof-top landing [4]	Detect elevated surfaces for simulated rooftop landing	Camera	• Only low altitude • Research grade (not robust) • Computationally demanding Implementation on GPU (Nvidia TX2 with Pascal GPU)
Autonomous Helicopter Testbed [5]	Detect hazard free landing area in camera frame	Camera	• Hazard detection & avoidance in low resolution elevation map (19x27 pixel) • No temporal map aggregation
Maplap [6]	ETH complete localization and mapping frame work	Camera	• Research-oriented algorithms that are executed off-line • Inefficient for on-board processing







Methodology

3D Reconstruction

- Perform feature tracking over consecutive frames and select candidate fames for dense 3D reconstruction (keyframes)
- Optimize camera poses in a refinement step (camera pose refinement)
- Perform rectification and dense real-time stereo for select image pairs with optimized poses

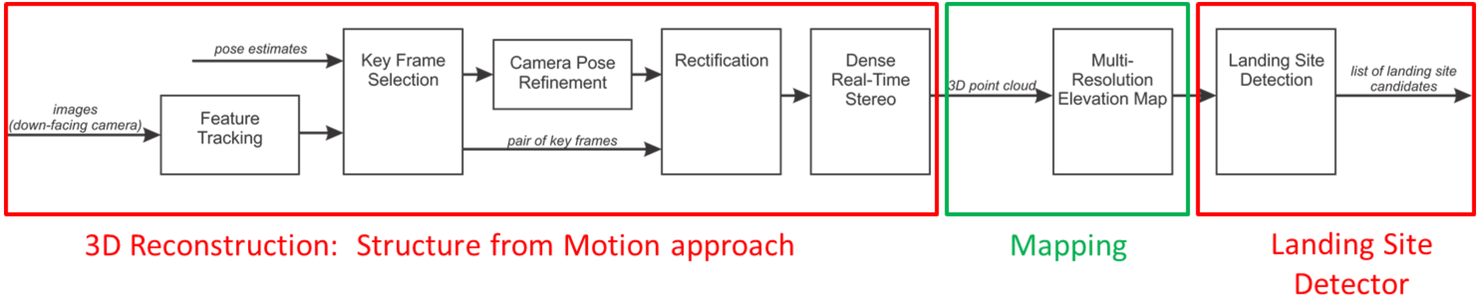
Map aggregation

- Local Multi-resolution elevation map (moves with vehicle) that adapts measurement update to pixel footprint on the ground

Landing Site Detection

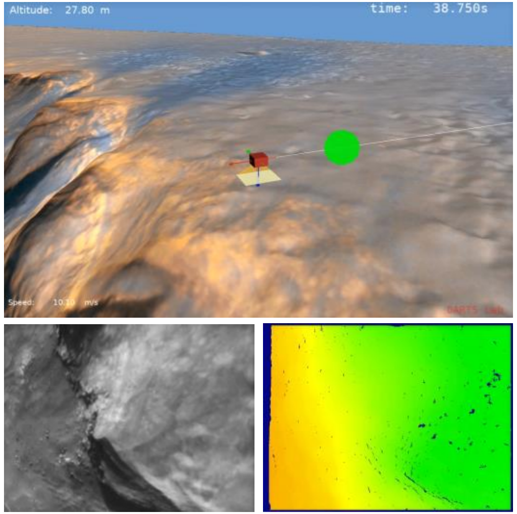
- Select suitable landing sites based on slope, roughness, and presence of landing hazards

Implementation on Snapdragon 820 as MSH Avionics target processor



Results

- Implemented two independent software modules within our navigation software *NAVINCI*
  - Structure from Motion (SFM)
  - Landing site detection (LSD)
- Full pipeline Testing on simulated data (including DARTS [2]) and data from UAS flights
- Currently evaluating performance



Flight in simulation environment. Top: Simulated UAS over Mars Victoria crater rim; Bottom left: Rectified image of down-facing camera; Bottom right: Associated disparity image (GT poses, no image noise; warmer colors are farther away)

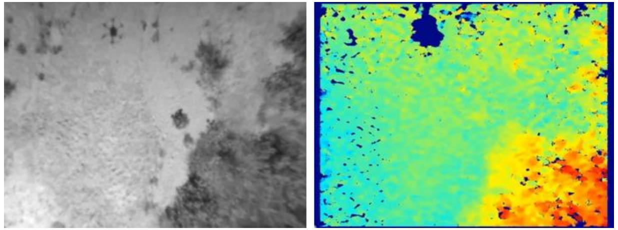
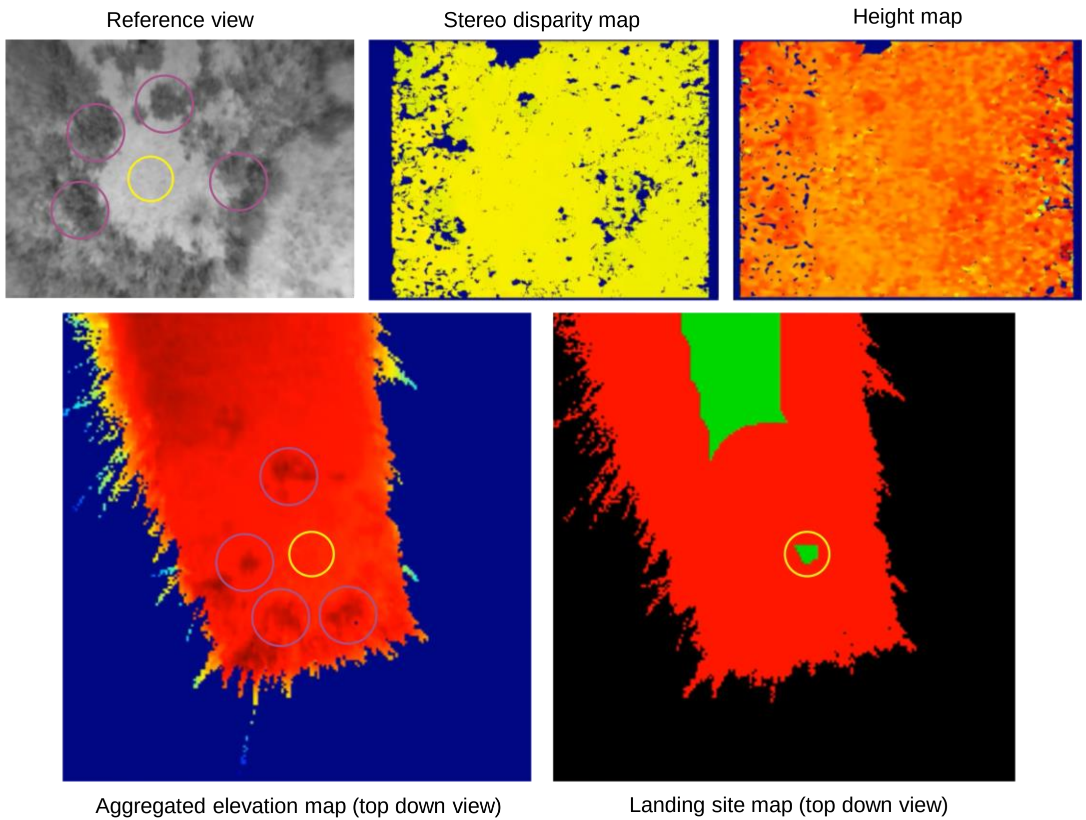


Illustration of 3D reconstruction: Left: Rectified most current view from downward facing camera on UAS; Right: Reconstructed height map (warm colors are closer to the camera).

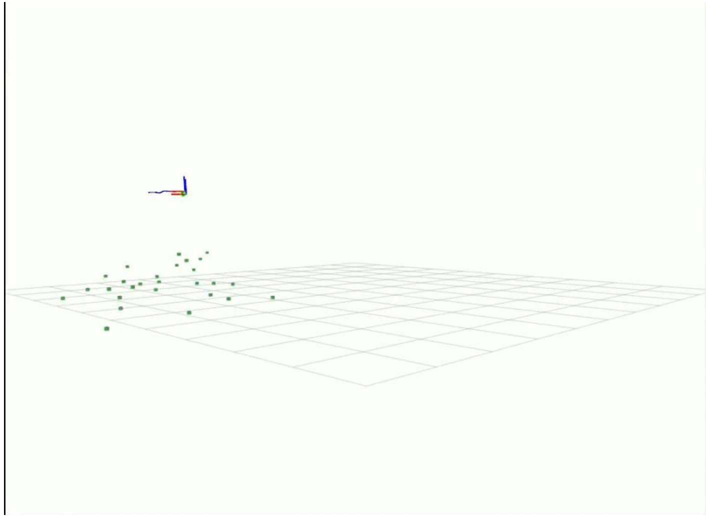
Results

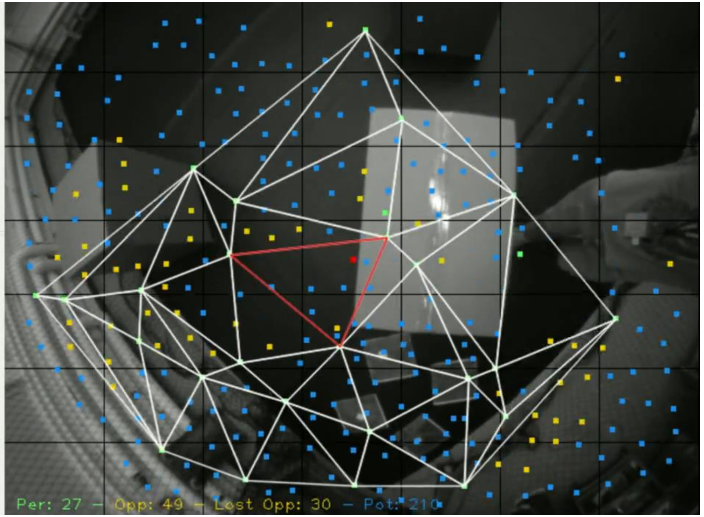


Landing Site Detection with annotated landing site map (bottom right). Green: safe landing site, red: landing hazard. Purple circles label selected landing hazards for visualization. Yellow circle labels detected landing site in between bushes (map is 100° rotated).

Other Results

State estimator (Range-VIO) stress case evaluation



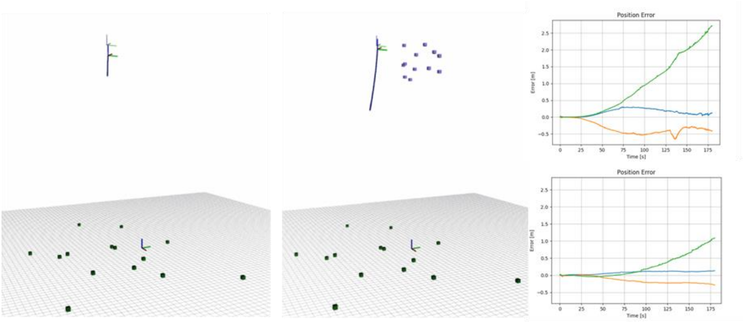


Range-VIO can observe scale without inertial excitation, even in highly-3D environment

- Ranged facet model assumes flat terrain between SLAM features
- Range outlier detection using Mahalanobis gating
- Outlier detection enables scale observation even when assumption is obviously violated

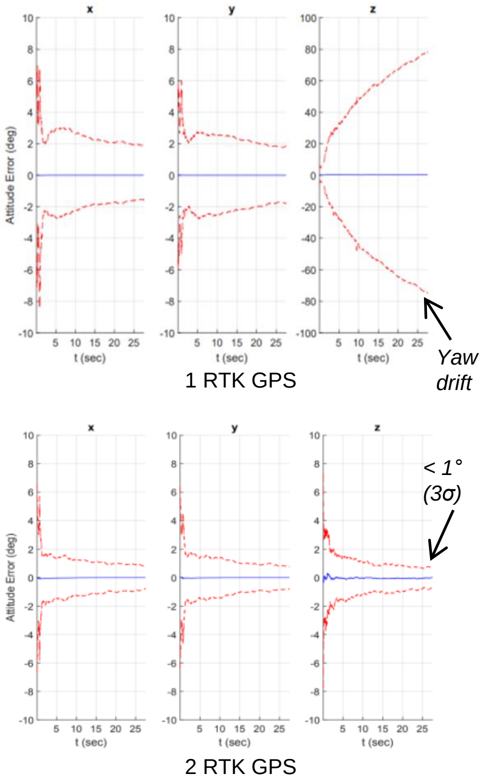
Other Results

Study: VIO with non-overlapping 2 cameras



Additional forward looking camera for state estimator. Flight scenario: Climb along a wall. Left: 1 camera used, position drifts when compared to ground truth; Middle: 2 cameras, position error reduced; Right: Position error is reduced by 250%.

Study: Dual-GPS / IMU ground truth filter (xGPS)



xEKF

- In-house light weight multi-sensor fusion
- Easily extendable, modular class architecture
- Iterated EKF parameters for high accuracy

xINIT

- In-flight initialization of state estimation without requiring inertial excitation
- Visual inertial Bundle Adjustment + LRF for metric pose initialisation

Next Steps

- Stress case testing of landing site detection with data acquired during UAS flights
- Optimize implementation for near real-time execution on MSH target avionics (Snapdragon 820)
- Demonstrate autonomous UAS landing with onboard landing site detection at previously unknown landing sites

- Focus of FY21: Develop global referencing software module

Publications and References

PUBLICATIONS

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